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DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 17/1
EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC LOADING FUNCTION--ETC(U)

JAN 74 D E GRAY

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"Experimental Determination of the Hydrodynamic Loading Functions for TMB Number 7 Fairing Shape," by Donald E. Gray (January 1974)

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034



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EXPERIMENTAL DETERMINATION OF THE
HYDRODYNAMIC LOADING FUNCTIONS
FOR TMB NUMBER 7 FAIRING SHAPE.

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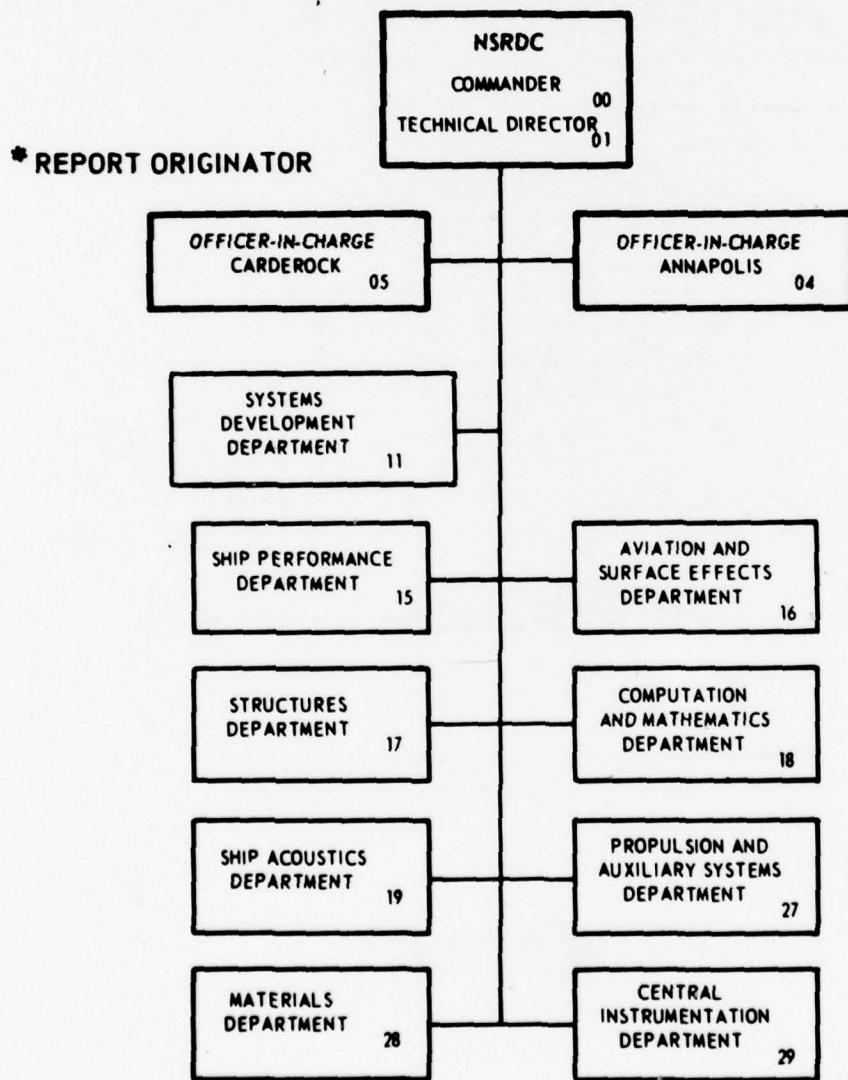
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The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
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NOTATION

A_0 Constant coefficient in hydrodynamic loading function;
 cf Equation (6)

A_n Coefficient of $\cos n\phi$ terms in hydrodynamic loading function;
 cf Equation (6)

B_n Coefficient of $\sin n\phi$ terms in hydrodynamic loading function;
 cf Equation (6)

C_R Cable fairing drag coefficient; cf Equations (1) and (3)

F General hydrodynamic loading function for either the normal
 or tangential direction

n Integer index; cf Equation (6)

R Drag per unit length of fairing when the fairing is normal to
 the free stream

R_n Reynolds number based on maximum fairing thickness; cf ON FOR
 Equation (2)

s Fairing model submergence (wetted length)

t Maximum fairing thickness

V Free stream velocity

X Normal hydrodynamic force

Y Lateral hydrodynamic force

Z Tangential hydrodynamic force

r Tangential hydrodynamic loading function; cf Equations (5)
 and (11)

Λ Normal hydrodynamic loading function; cf Equations (4) and (10)

ν Kinematic viscosity of fluid

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NOTATION (cont)

ρ Mass density of fluid

ϕ Cable angle (acute angle between Z force direction and direction of motion; cf Figure 4)

ADMINISTRATIVE INFORMATION

This work was funded by the Naval Ship Engineering Center under Subproject F14222, Naval Ship Research and Development Center Work Unit Number 1-1548-204.

INTRODUCTION

The Naval Ship Research and Development Center (NSRDC) established a research project under the Submarine Towed Communications Program directed toward the development of fundamental design information for future submarine towed systems. This work is in accordance with a continuing effort at the Center to improve techniques for predicting the steady-state and dynamic characteristics of cable-towed systems.

The differential equations describing the two-dimensional steady-state configuration and forces of a cable-body system are well defined within the limits of certain simplifying assumptions.^{1*} Solutions to these equations can be obtained numerically through digital computation provided the body characteristics, cable loading functions, and cable drag coefficients are specified.² An expression representing the general form of the cable loading function has been developed at the Center.³ However, to obtain the loading functions for a specific faired cable, the coefficients for the aforementioned expression must at present be determined experimentally. To date, experiments to determine

*References are listed on page 23.

cable loading have been conducted on numerous faired-cable designs (References 4, 5, 6, 7, 8, 9, and 10). The experimental approach consists of towing a rigid faired-cable model in the David Taylor Model Basin at various speeds, cable angles, and model submergences and measuring the hydrodynamic forces using the DTMB Cable-Fairing Dynamometer. Data obtained from these experiments are non-dimensionally normalized and processed with a curve-fitting computer program to obtain mathematical expressions for the loading functions and drag coefficients.

↓ This report is concerned with similar experiments on the TMB Number 7 Fairing Shape including experiments for a cable angle of zero degrees to obtain the lower boundary value of the tangential loading function. This report describes the subject fairing model, the cable fairing and towing girder dynamometers, the instrumentation, the experimental procedure and method; gives sample plots used to obtain the loading expressions of normal and tangential forces versus model submergence for various speeds; presents graphically, fairing drag coefficient versus Reynolds number and normal and tangential loading functions; and provides the mathematical expressions, with coefficients, for the loading functions and drag coefficients. ↗

DESCRIPTION OF FAIRING MODEL

The basic model consists of a five-segment aluminum strut having a TMB Number 7 Fairing section shape as described in Reference 11.

Details are shown in Figure 1. Additional physical characteristics of the fairing model are given in Table 1.

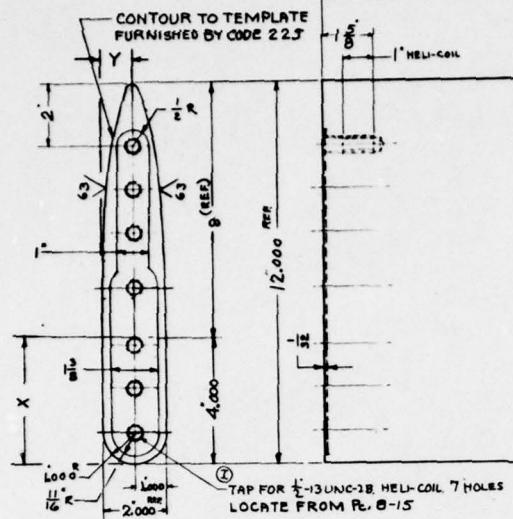
TABLE 1
PHYSICAL CHARACTERISTICS OF FAIRING MODEL

Section shape	TMB No. 7
Chord, inches	12.00
Maximum thickness, inches	2.00
Section fineness ratio	6
Ratio of wetted surface area to projected frontal area	12.78
Model length (cable fairing dynamometer), inches	89.25
Model length (towing girder), inches	113.25

The model was designed to be configured for both the cable fairing and towing girder dynamometers. The configuration for the cable fairing dynamometer consisted of the long 7-1/2-foot model segment with the strut plate and is shown attached to the dynamometer in Figure 2. The configuration for the towing girder dynamometer consisted of the long model segment suspended, leading edge up, below the girder by two standard 4-1/2-foot ogive struts. The length of the model was variable by the addition of the short segments. The "full length" configuration is depicted in Figure 3. Nose and tail fairings were added for streamlining and fillets were also added at the model/strut interfaces.

DESCRIPTION OF DYNAMOMETER AND INSTRUMENTATION

The DTMB Cable Fairing Dynamometer is shown in Figure 2 with the



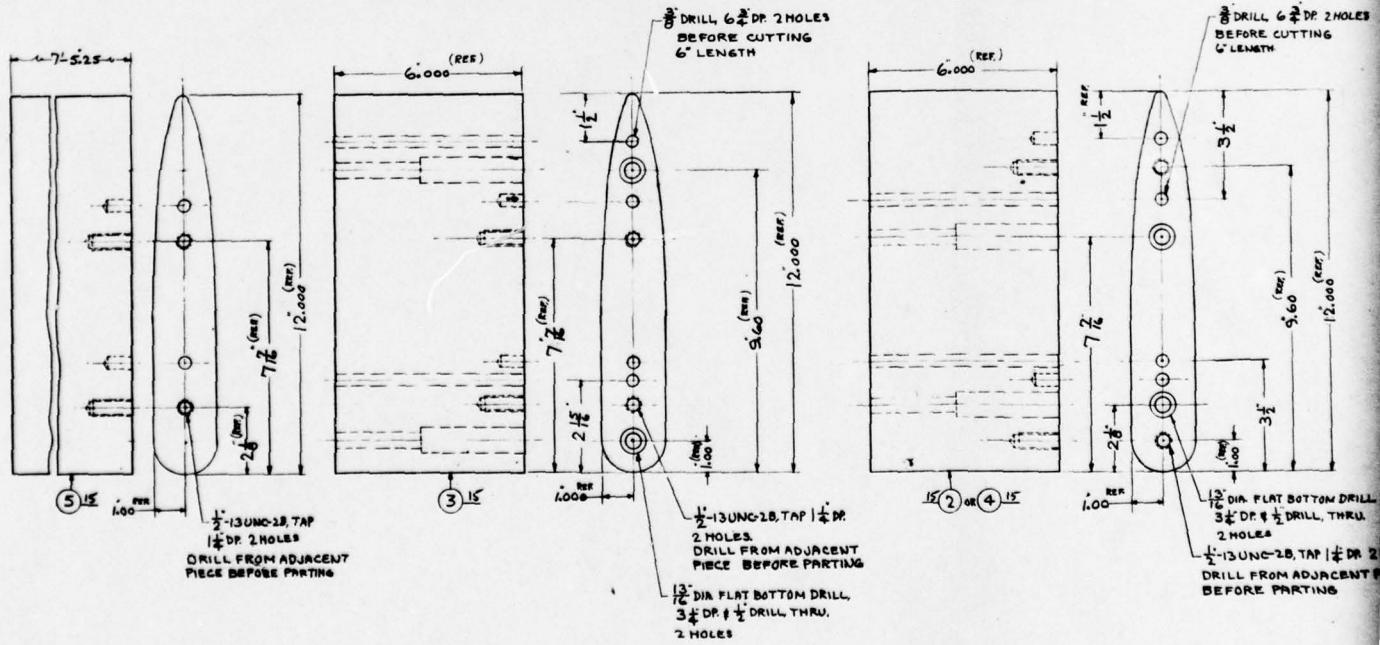
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24"

TMB No 7		
OFF SETS		
STA.	X	Y
1	4.00	6.000
2	4.00	.9995
3	5.60	.9935
4	6.40	.9786
5	7.20	.9500
6	8.00	.9021
7	8.80	.8313
8	9.60	.7323
9	10.40	.6000
10	10.80	.5176
11	11.20	.4241
12	11.60	.3206
13	11.80	.2127
14	12.00	.0000

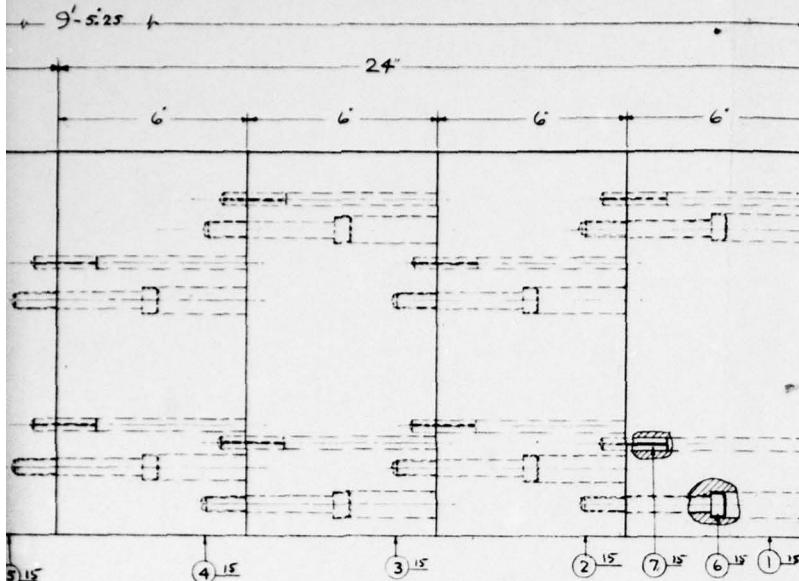
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3/8 DRILL, 6 3/4 DP. 2 HOLE
BEFORE CUTTING

$\frac{3}{8}$ DRILL, 6 $\frac{3}{4}$ DP. 2 HOLES
BEFORE CUTTING

A technical drawing of a flat bottom drill bit. The bit has a central longitudinal axis. At the top, there are two circular features, each containing three small circles. Along the central axis, there are four circular features, each containing three small circles. The drawing includes several dimensions: a total length of 12' 0" (144 inches), a width of 2' 8" (32 inches), and a thickness of 1' 11 1/2" (75.5 inches). A side view shows a height of 9' 6 1/2". The drawing also indicates a 'FLAT BOTTOM DRILL' with a '1/2" DIA. FLAT BOTTOM DRILL' and '3 1/2" D.P. & 1/2" DRILL, THRU. 2 HOLES'.

L 1-13 UNG-2B, TAP 1/4 DR. 2 HOLES
DRILL FROM ADJACENT PIECE
BEFORE PARTING

		REVISIONS			
REV.	DATE	DESCRIPTION	BY	DATE	APPROVED
I	SD	7 TAPPED HOLES FOR $\frac{1}{2}$ " HELI-COILS ADDED TO PC 5-15	W.L.K.	20	8/
	PC 8 ADDED	PC 9-10 ADDED, $\frac{1}{16}$ " DEEP RECESS ADDED TO PC 5		66	12/
II	PC 8, MATH 410 WAS 921		N.D.	MAY	

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SUGGESTED MACHINING PROCEDURE

- 1) MACHINE FROM ONE LENGTH ALLOWING ADDITIONAL LENGTH FOR PARTING OF END PIECES 1; 2; 3. & 4
(DIMENSIONS SHOWN ARE FINISHED DIM.)
- 2) BORE FOR $\frac{3}{8}$ " REAMED HOLES, AND $\frac{1}{2}$ " BOLTS STARTING WITH PIECE NO. 1. (BORE PIECE 1 TO GIVE 6" LENGTH, THEN BORE PIECE NO. 2 AND PART, AND SO FORTH IN RESPECTIVE ORDER)
- 3.) TEMPLATE SUPPLIED BY CODE 225.

3.) TEMPLATE SUPPLIED BY CODE 225

DRILL #1 $\frac{1}{2}$ IN CBORE $\frac{3}{8}$ DP, 7 HOLES

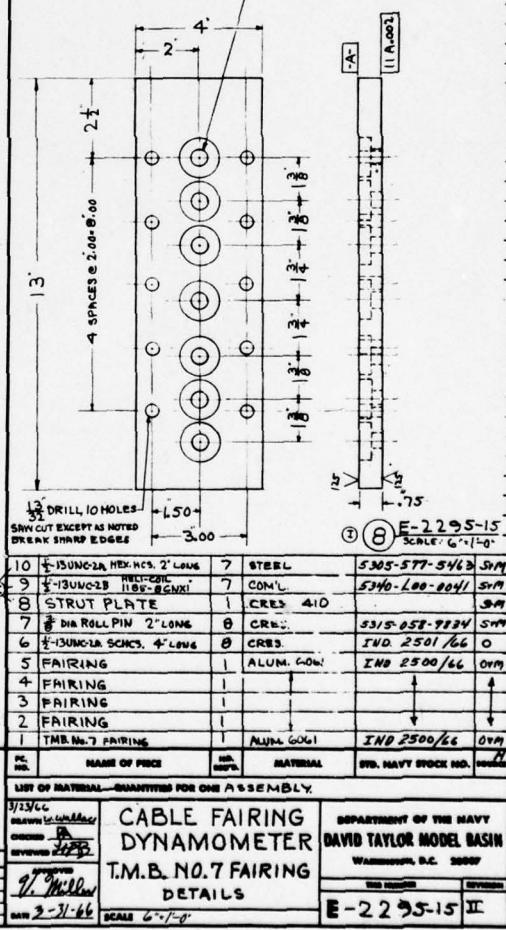
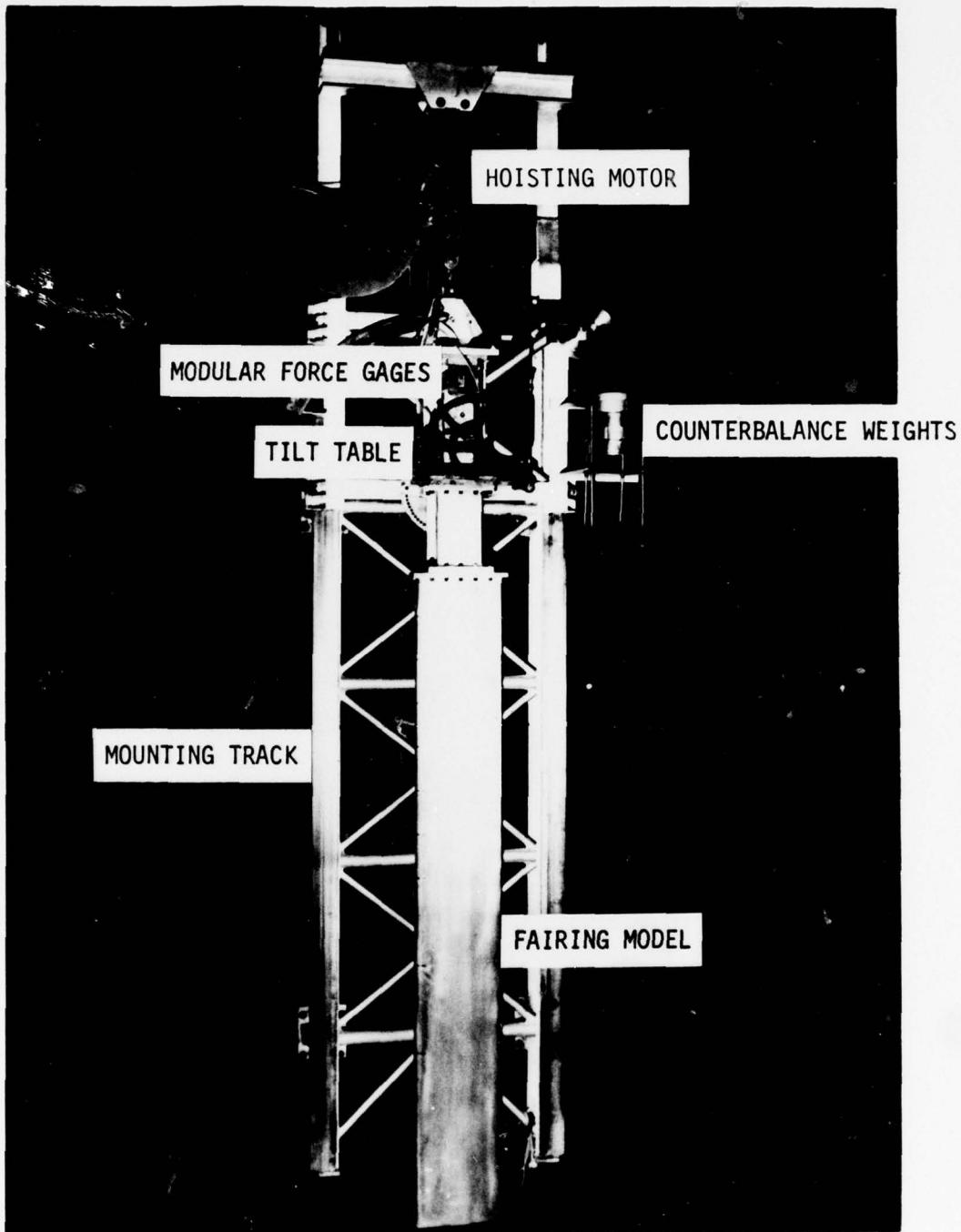


Figure 1 - Fairing Model Drawing



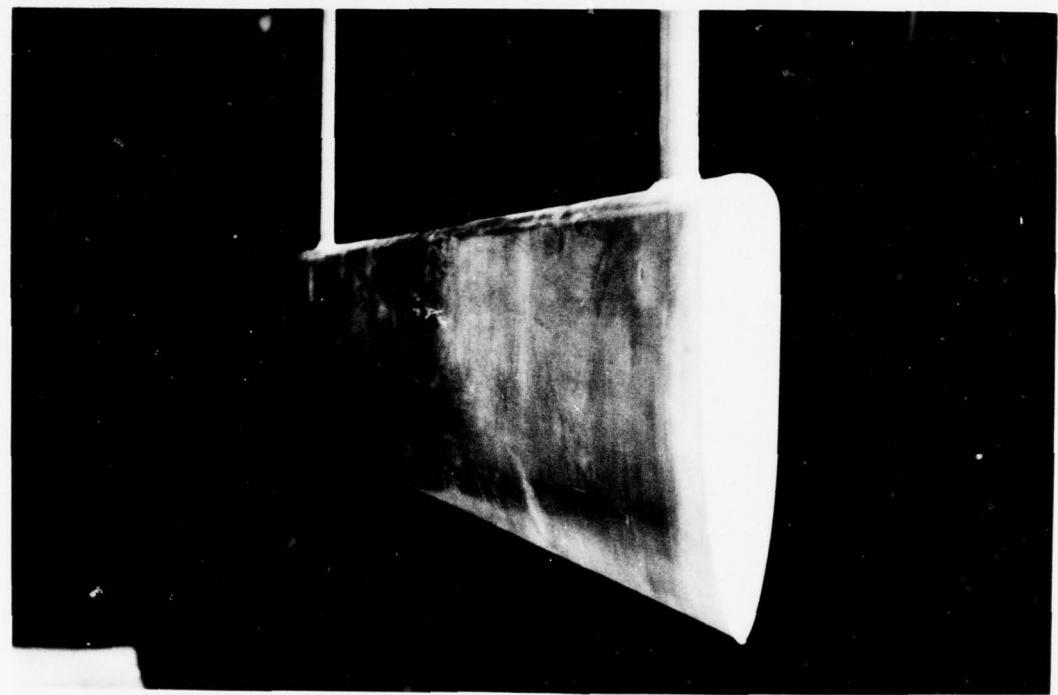
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Figure 2 - Cable Fairing Dynamometer with Model Attached



PSD 338419

Figure 3a - Side View



PSD 338498

Figure 3b - Quarter View

Figure 3 - "Full Model" Configuration with Ogive Struts

fairing model attached. The normal force, X, lateral force, Y, and tangential force, Z, on the model, as depicted in Figure 4, are sensed by separate 4-inch-cube modular force gages of the type described in Reference 12. Interchangeable gages with capacities ranging from 50 to 1000 pounds are available so that high accuracy can be maintained over a range of speeds. However, the dynamometer structure limits each of the three component forces to 500 pounds.

The dynamometer tilt-table angle is adjustable so that the model cable angle, ϕ , relative to the free stream may be varied from 30 degrees to 90 degrees in 5-degree increments. The vertical position of the model and tilt table also is adjustable by means of an electric hoist so that model submergence may be varied from zero to approximately 7 feet. A weight-pan system provides a means of counterbalancing the model weight on the gages at each submergence and cable angle. Model yaw angle also is adjustable to provide proper alignment with the flow.

Instrumentation used with the cable fairing dynamometer included a 50-pound-capacity gage for the X force, a 1000-pound-capacity gage for the Y force, and a 50-pound-capacity gage for the Z force; a three-channel modular-force-gage control unit, two integrating digital voltmeters for readout of the X and Z forces and a strip-chart recorder for monitoring the Y force. A magnetic pickup and digital counter were used to indicate towing carriage speed and a digital printer was used to record the X force and Z force. The instrumentation console used is shown in Figure 5.

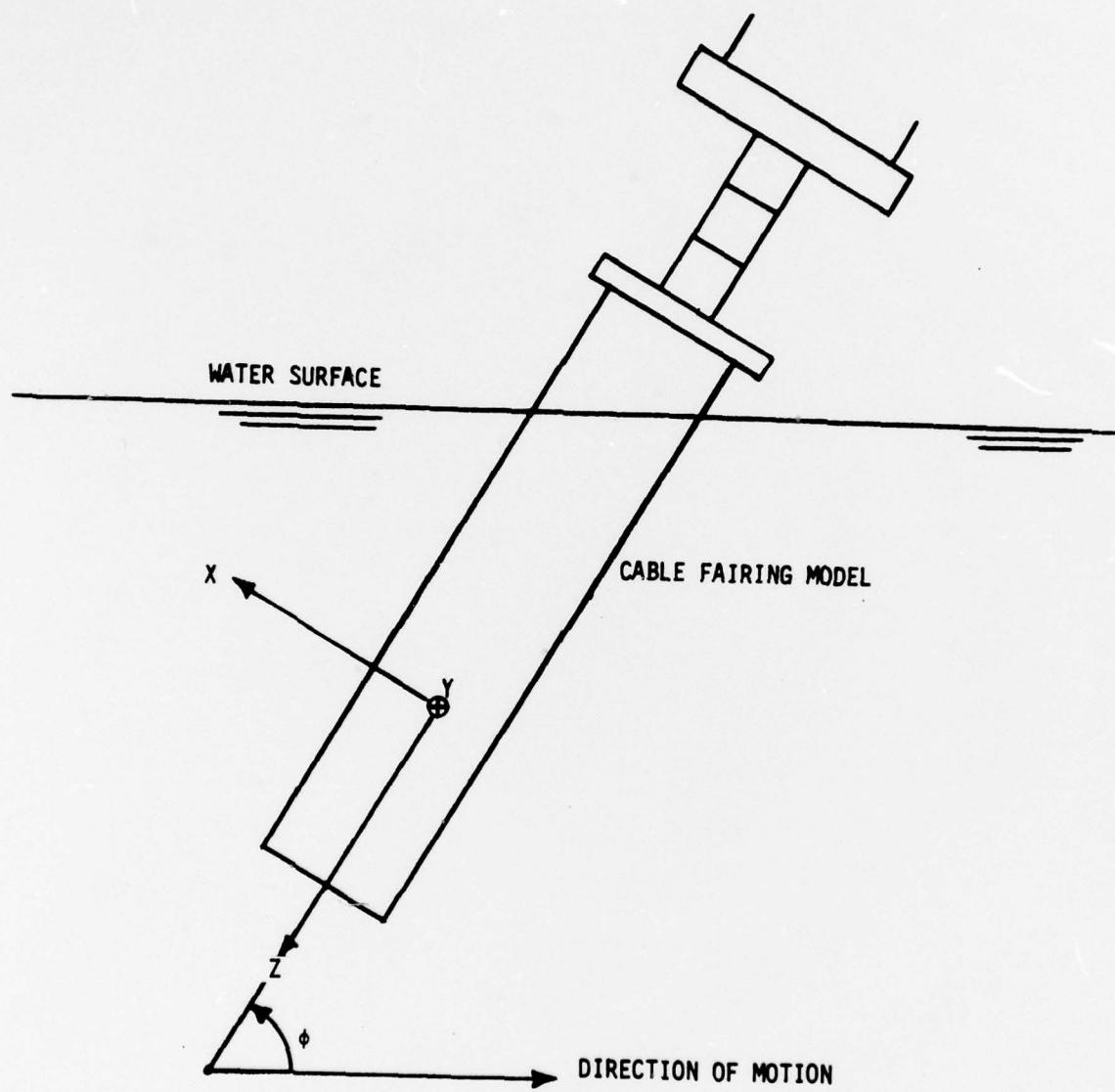
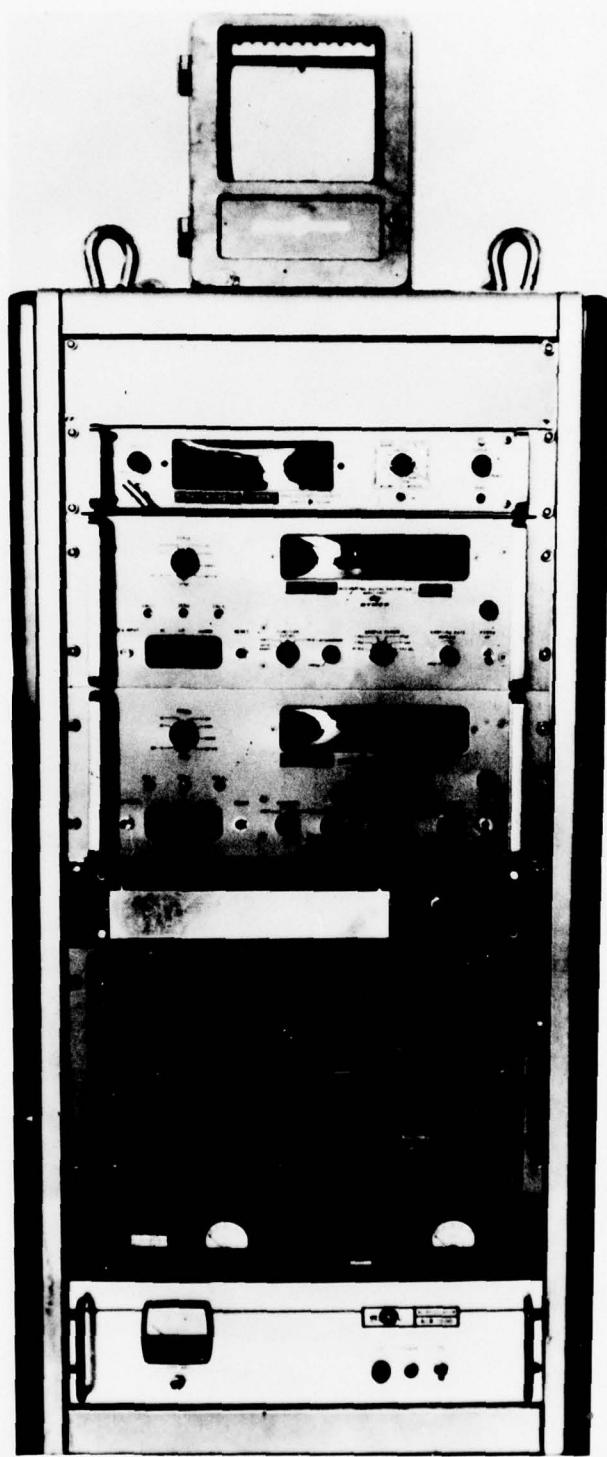


Figure 4 - Force Coordinate System



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Figure 5 - Instrumentation Console for Cable Fairing Dynamometer

The estimated accuracy of the force measurement system is ± 0.25 pound for the X and Z forces and ± 5 pounds for the Y force. The accuracy of the speed measurement is ± 0.05 knot.

The towing girder dynamometer is of the floating-frame weighing type and is illustrated diagrammatically in Figure 6. The dynamometer girder carries a long horizontal floating beam in pendulum fashion on two pairs of vertical arms terminating in flexible springs. A counterweight at the upper end of a vertical swinging arm mounted on the girder and attached to the floating beam maintains the beam in equilibrium at any position between the limit stops. The model resistance is transmitted as a horizontal force through the upper flexible link to the T-shaped balance, where it is balanced by weight, W. When the model resistance is not equal exactly to a unit weight, W, the difference is taken up by the resiliency of the flexible spring supports; the exact amount being recorded on the drum through the lower link and recording arm shown. A variable strength electro-magnetic dampener is incorporated to minimize model surge motions. The drag measurement is estimated to be accurate to ± 1.5 percent.

EXPERIMENTAL PROCEDURE

The model was first towed with the cable-fairing dynamometer in the high-speed basin at various cable angles ranging from 30 degrees to 90 degrees in approximately 10 degree increments. At each cable angle, the model submergence was varied from 24 inches to 84 inches

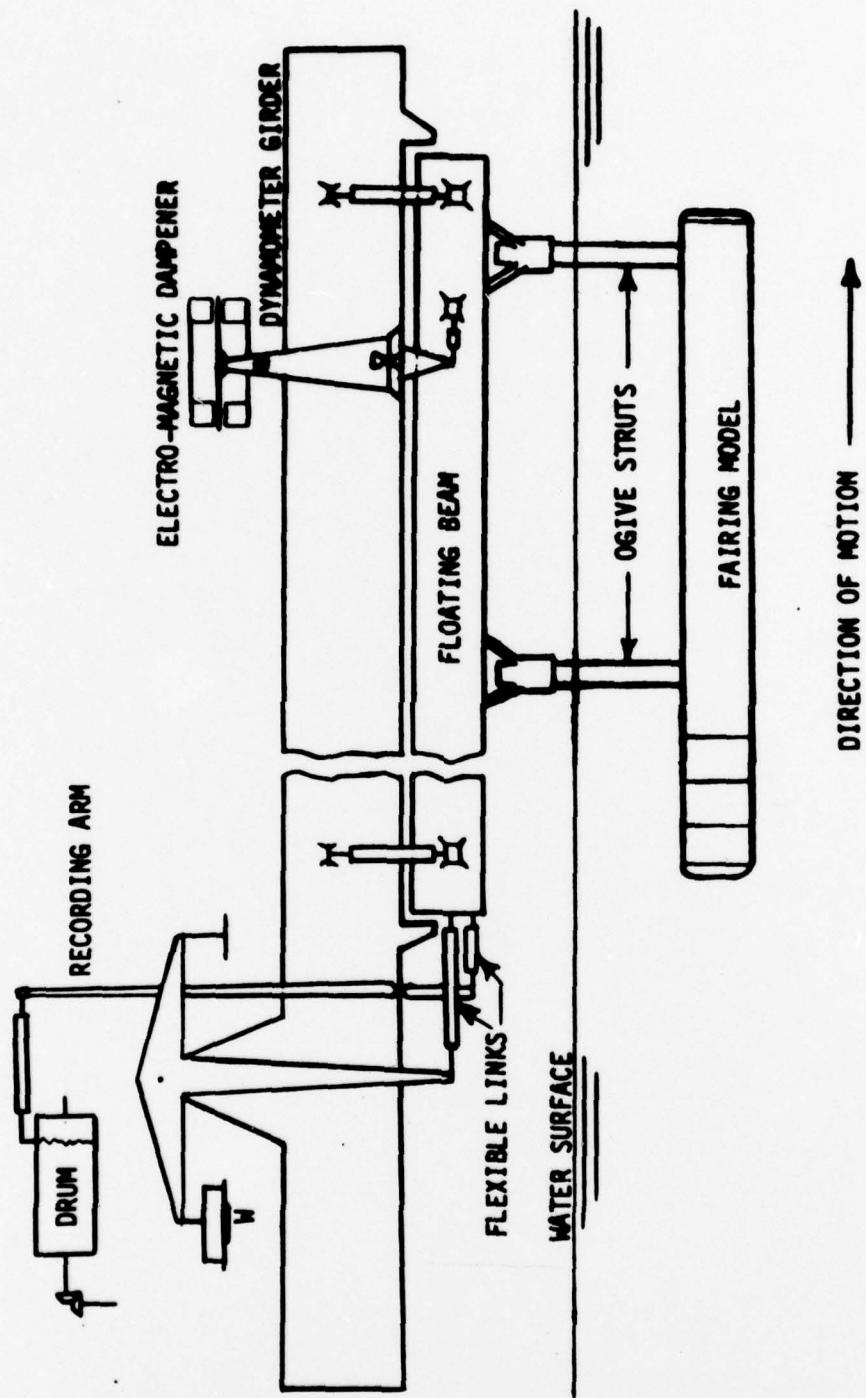


Figure 6 - Schematic Arrangement of Towing Girder Dynamometer

in multiples of 6 inches for towing speeds of 5 and 8 knots. Additional speeds of 2, 3, 4, 6, 10, and 13 knots also were run at a cable angle of 90 degrees over the aforementioned submergence range. The X, Y, and Z forces and towing speed were measured for each run condition. The Y force reading was used mainly as a basis for aligning the model with the flow to minimize the Y force. It also provided a means of monitoring model lateral oscillations at each run configuration.

The model also was towed from the floating girder dynamometer in the deep-water basin to obtain zero degree cable angle data. The procedure consisted of first towing the long model segment at speeds of 5, 8, and 13 knots and measuring the total drag force at each speed. Subsequent runs were conducted adding each of the four 6-inch segments in turn and measuring the total drag force at each speed.

HYDRODYNAMIC FORCES

The measured hydrodynamic forces were generated by a three-dimensional surface-piercing model. Therefore, the data contain both end effects and surface effects. The desired two-dimensional hydrodynamic forces were derived from these data by the following method. The X and Z forces were plotted as a function of model submergence (wetted length) for each angle and speed. As model submergence is increased, a length is reached after which both the X and Z forces became linearly dependent on submergence for a constant speed and angle, i.e., end and surface effects became essentially constant.

Slopes of the linear portion of the force-submergence curves were determined by the method of least squares for each angle and speed. Typical plots are given in Figures 7 and 8 for the X and Z forces, respectively. These slopes, $\frac{\Delta X}{\Delta S}$ and $\frac{\Delta Z}{\Delta S}$, represent the two-dimensional hydrodynamic forces per unit length acting on the fairing model and are tabulated as Table 2.

TABLE 2
TWO-DIMENSIONAL HYDRODYNAMIC FORCES

Cable Angle, degrees	Speed, knots	Normal, pounds per foot	Tangential, pounds per foot
30.62	5	0.5266	0.5460
	8	1.0267	1.2368
40.58	5	0.6842	0.4868
	8	1.5344	1.0652
50.50	5	0.8641	0.4655
	8	1.8782	0.9044
60.12	5	1.1964	0.3630
	8	2.4649	0.7266
70.10	5	1.4026	0.2255
	8	No data, large lateral oscillations	
79.82	5	1.3077	0.2071
	8	2.8169	0.2715
79.92	13	6.8185	0.4742
	5	1.2942	0.1997
90.00	8	2.8169	0.2715
	13	6.8185	0.4742
	5	1.2915	0.0152
	8	2.8386	-0.0175
	13	6.6157	0.0108

DRAG COEFFICIENT

The fairing drag coefficient, C_R , and corresponding Reynolds number, R_h , were determined for each speed using the following expressions:

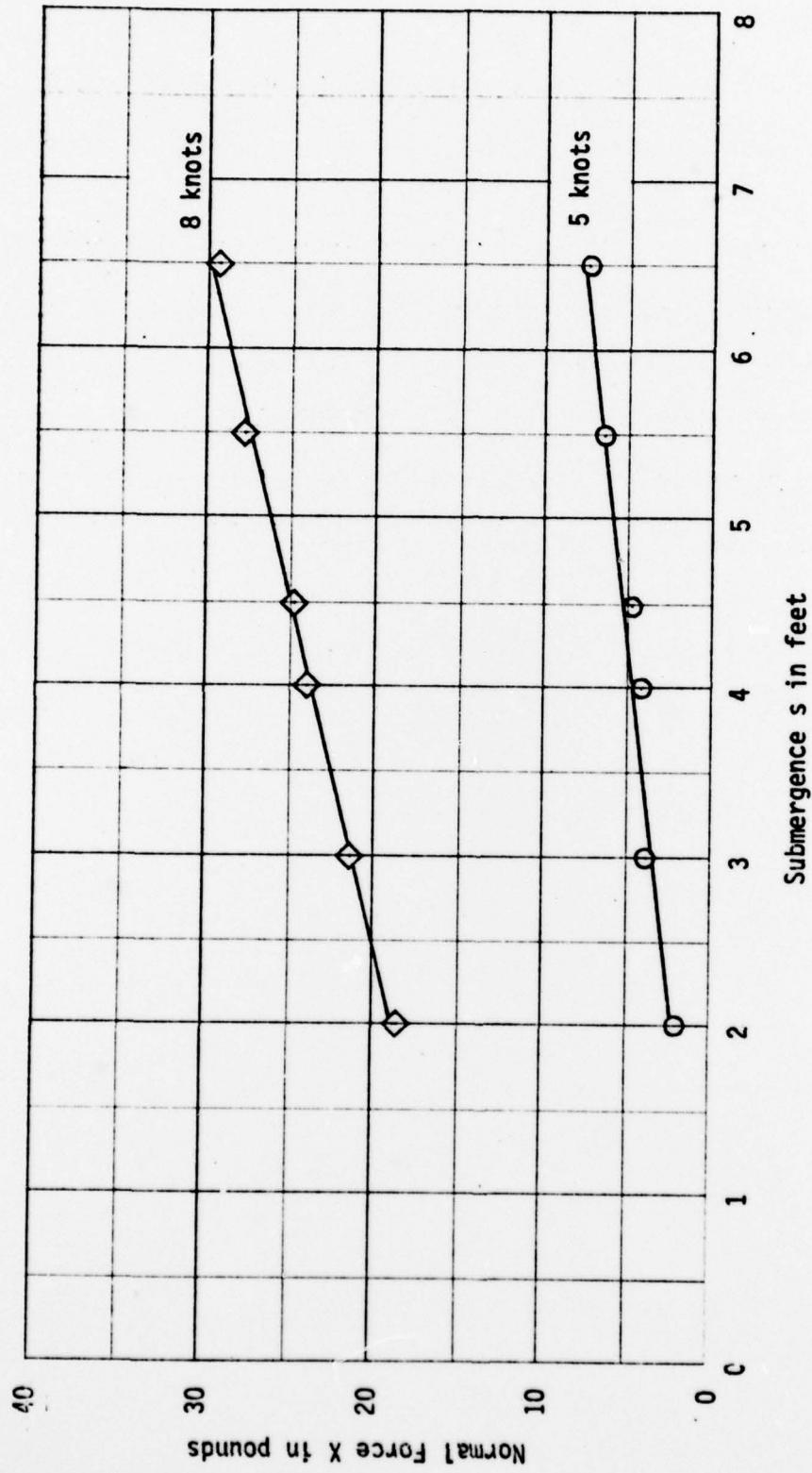


Figure 7 - Normal Force Versus Submergence for a Cable Angle of 60.12 Degrees

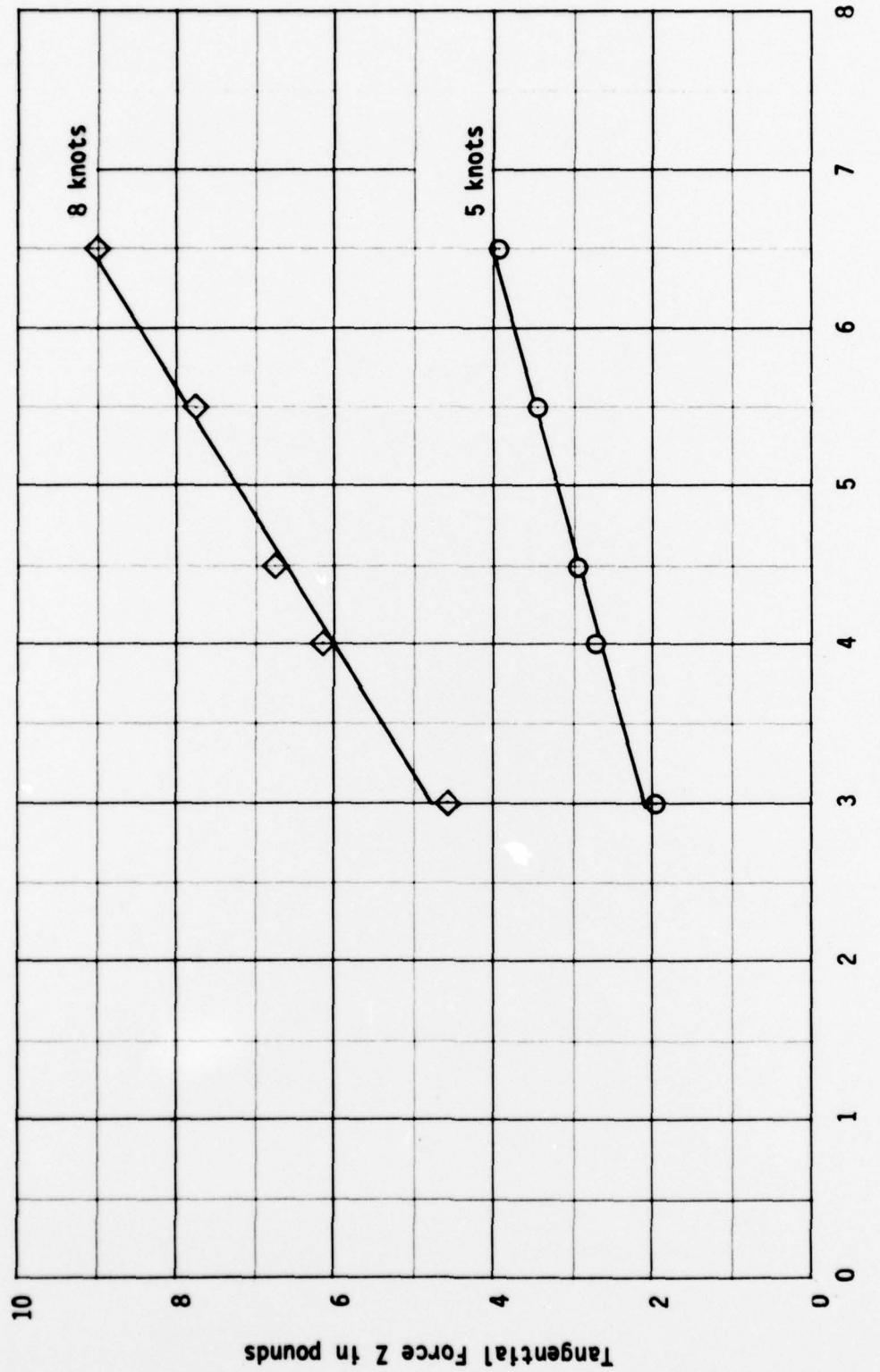


Figure 8 - Tangential Force Versus Submergence for a Cable Angle of 30.62 Degrees

$$C_R = \frac{R}{(1/2)\rho t V^2} \quad , \quad (1)$$

and

$$R_n = \frac{Vt}{v} . \quad (2)$$

The resulting Reynolds numbers and drag coefficients are given in Table 3. Applying a least-squares fit to the data in Table 3 yields the following expression for the variation of drag coefficient with Reynolds number:

$$C_R = 3.74 R_n^{-0.296} \quad (3)$$

The curve representing this expression is given in Figure 9.

TABLE 3
REYNOLDS NUMBERS AND DRAG COEFFICIENTS

Speed, knots	$R_n \times 10^{-5}$ *	C_R
2	0.562	0.145
3	0.844	0.133
4	1.125	0.122
5	1.406	0.111
6	1.687	0.107
8	2.250	0.096
10	2.812	0.092
13	3.656	0.085

*NOTE: Basin water temperature was 74 degrees Farenheit

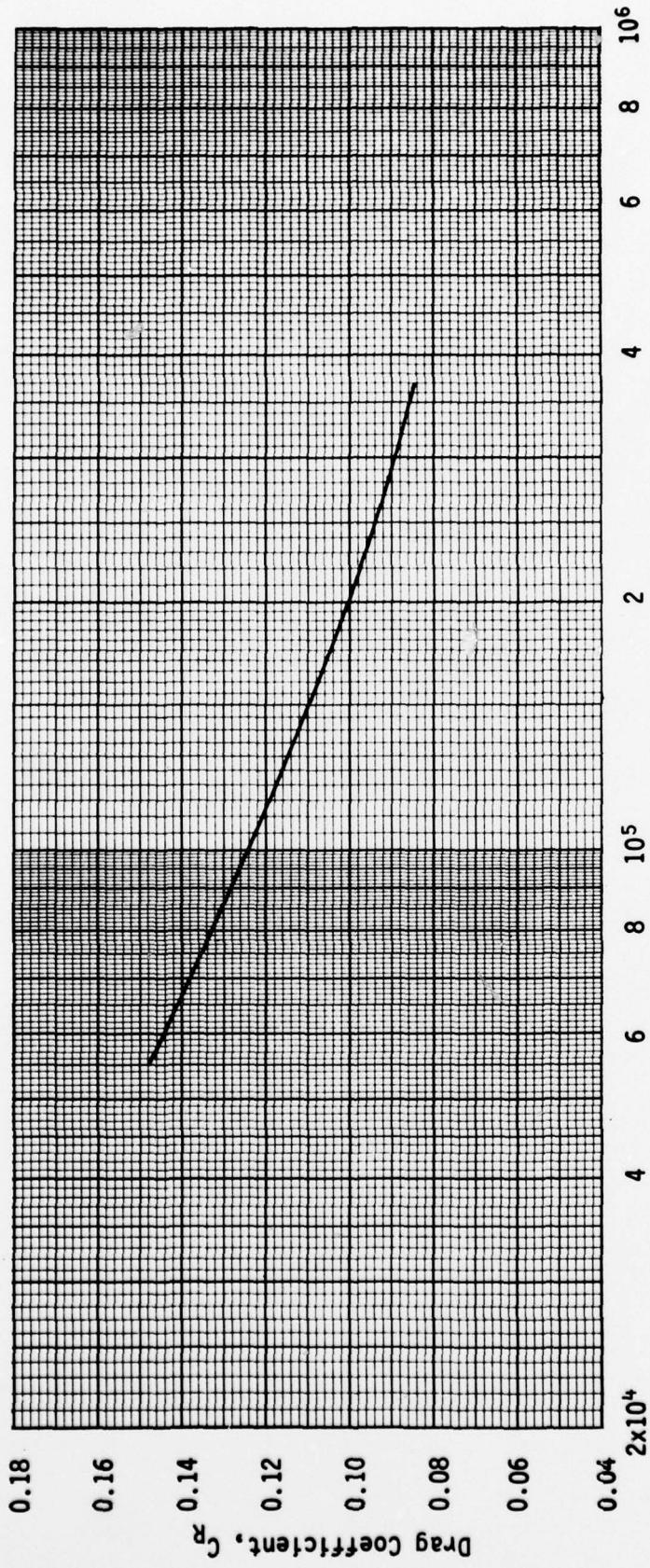


Figure 9 - Drag Coefficient Versus Reynolds Number, R_η

HYDRODYNAMIC LOADING FUNCTIONS

The hydrodynamic loading functions are defined as the ratios of the steady-state, two-dimensional, hydrodynamic forces acting on an element of fairing at angle ϕ to the drag per unit length of fairing when the fairing is normal to the free stream, R (where R is the drag at $\phi = 90$ degrees). Therefore, the normal and tangential loading functions at an angle ϕ are respectively

$$\Lambda(\phi) = \frac{X(\phi, R_n)}{X(90, R_n)} = \frac{X(\phi, R_n)}{R(R_n)}, \quad (4)$$

and

$$\Gamma(\phi) = \frac{Z(\phi, R_n)}{R(R_n)}, \quad (5)$$

where, $0^\circ \leq \phi \leq 90^\circ$.

As expressed in Equations (4) and (5), these loading functions are assumed to be dependent only on the cable angle for a given fairing geometry. The loading functions variation with cable angle may be represented analytically by selected combinations of the first few terms of the infinite series,³

$$F(\phi) = A_0 + \sum_{n=1}^{\infty} A_n \cos n\phi + \sum_{n=1}^{\infty} B_n \sin n\phi. \quad (6)$$

The following method was used to generate the particular trigonometric expressions for both the normal and tangential loading functions. The two-dimensional hydrodynamic forces per unit length given in Table 2

were normalized by dividing by the corresponding R value at each Reynolds number obtained from Equation (7).

$$R = 1.87 \frac{\rho v^2}{t} R_n^{1.704} \quad (7)$$

This expression represents the values of R resulting from the least squares fit of C_R versus R_n , Equation (3), and was derived by solving Equation (2) for V; substituting this expression and Equation (3) into Equation (1) for V and C_R , respectively; and solving the resulting expression for R.

A curve-fitting process using the method of least squares was performed on the two sets of resulting loading values. The process consisted of generating the coefficients for selected combinations of terms in Equation (6) for which the following loading boundary conditions were satisfied:

$$\Lambda(0^\circ) = 0, \quad (8A)$$

$$\Lambda(90^\circ) = 1, \quad (8B)$$

$$\frac{d\Lambda(90^\circ)}{d\phi} = 0, \quad (8C)$$

and

$$r(90^\circ) = 0. \quad (9)$$

The expressions resulting for $n \leq 2$ are

$$\Lambda(\phi) = 0.2675 + 0.4650 \sin \phi - 0.2675 \cos 2\phi \quad (10)$$

and

$$\begin{aligned} \Gamma(\phi) = & -2.3034 + 2.4536 \cos \phi + 2.4712 \sin \phi \\ & + 0.1678 \cos 2\phi - 0.8232 \sin 2\phi \end{aligned} \quad (11)$$

where Λ and Γ are the normal and tangential loading functions, respectively.

The foregoing expressions are plotted in Figures 10 and 11.

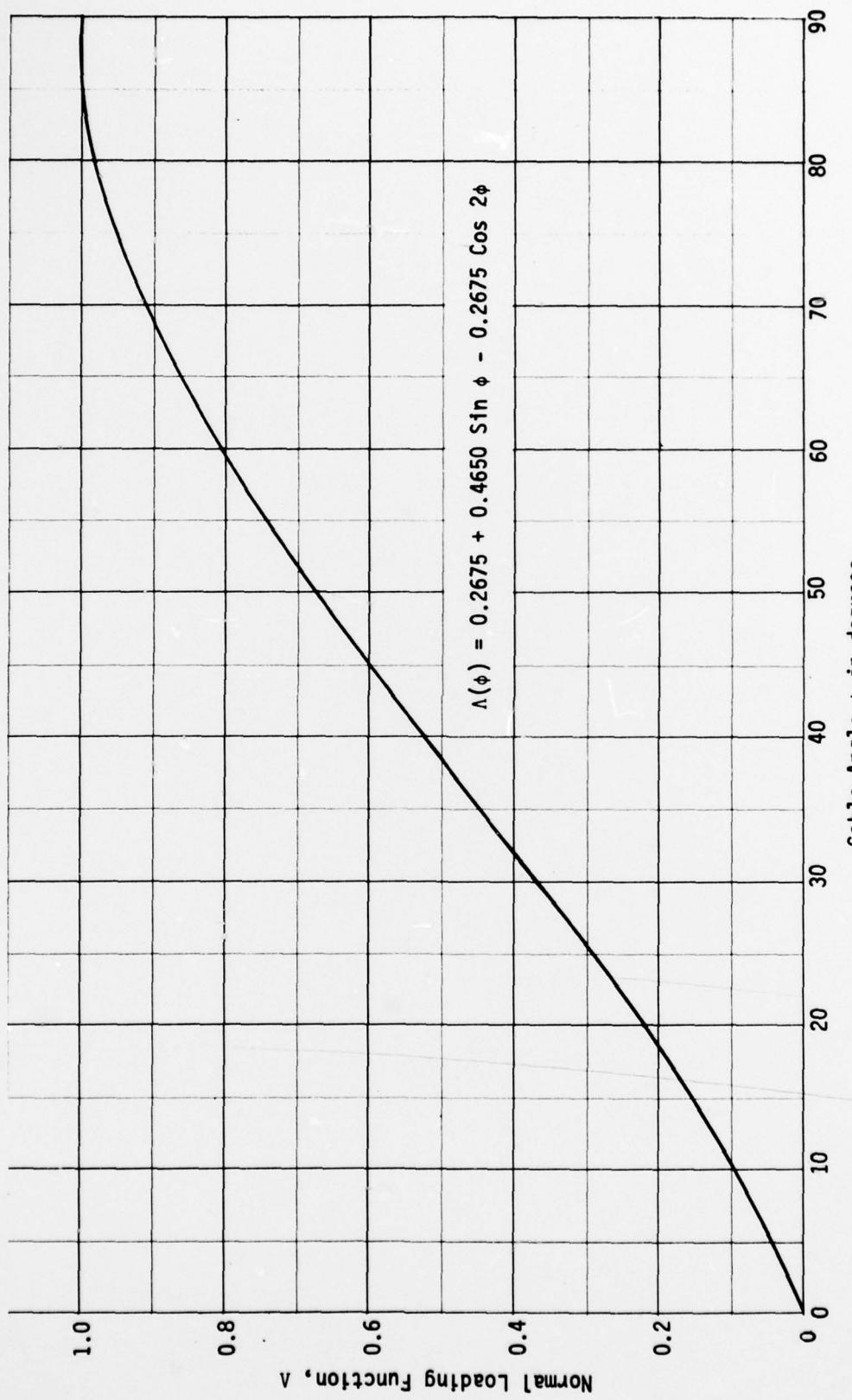


Figure 10 - Normal Loading Function Versus Cable Angle

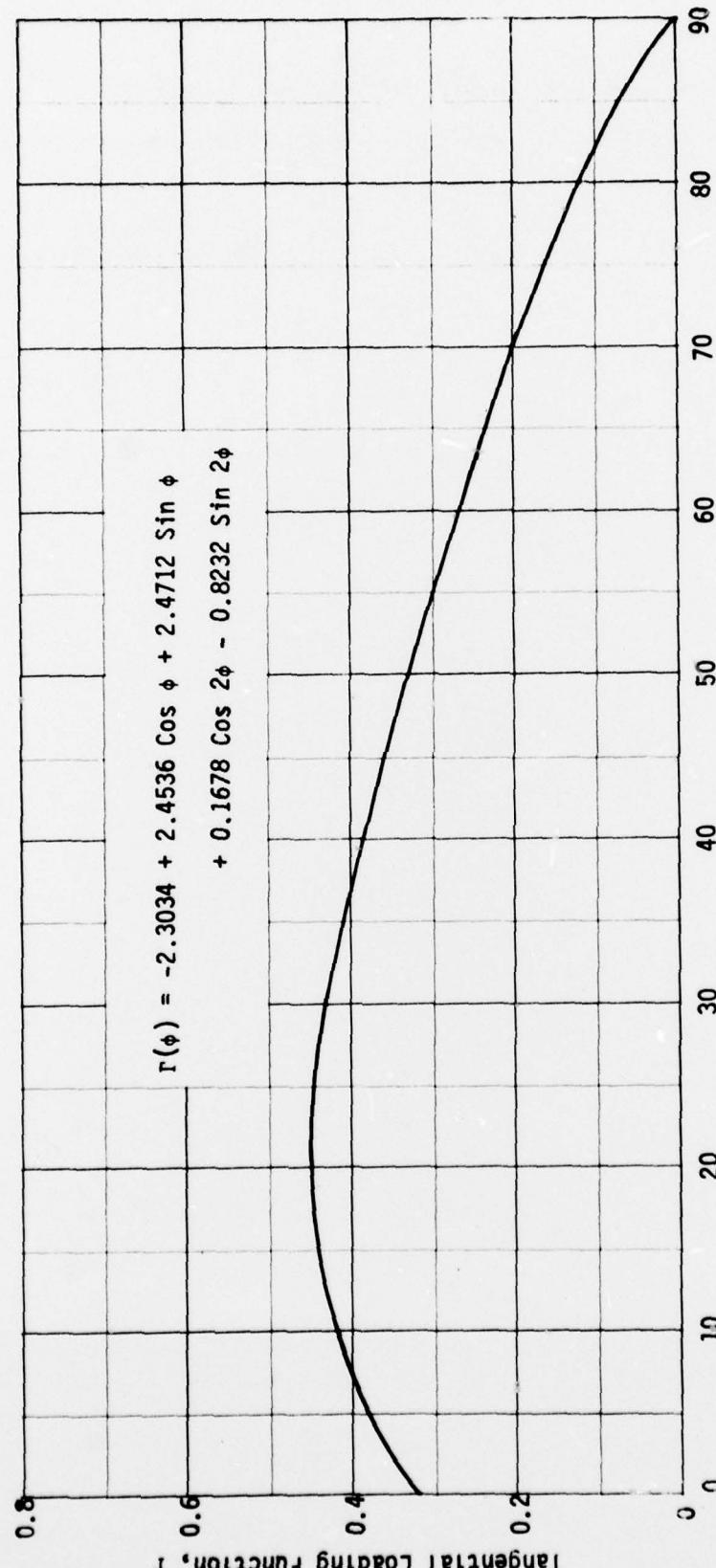


Figure 11 - Tangential Loading Function Versus Cable Angle

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